APPENDIX F

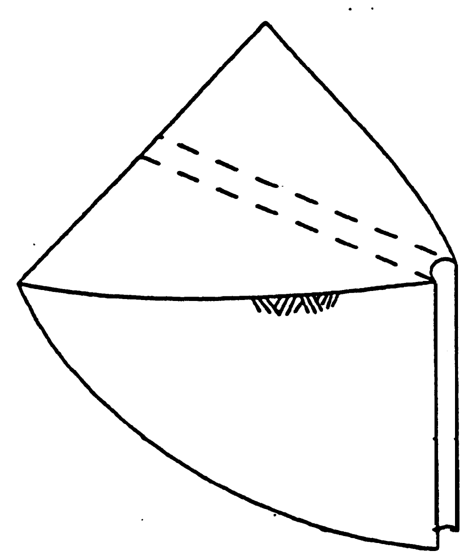
Occasionally it will be necessary to review soldier pile shoring designs based on a combination of cohesionless and cohesive soils. To aid in the review of systems with a combination of soils the California Transportation Materials and Research Laboratory has furnished guidelines for the analysis of soldier piles.

When soldier piles are spaced 4 or more pile diameters apart they can be treated as individual piles. Piles spaced closer than 2 pile diameters should be treated as a pile group (or as a sheet pile wall). For soldier piles spaced between 2 and 4 pile diameters prorate between the analysis for a sheet pile wall condition (which represents 1 soldier pile diameter spacing) and the condition for 4 pile diameter spacing single pile analysis.

Above the plane of the excavation depth the active pressures and surcharge loadings act on a length of wall equal to the soldier pile spacing. Below the excavation depth the active and surcharge pressures act on an expanded effective width (d) of the soldier pile. The expanded effective soldier pile width, incorporates the advantages of increased passive soils resistance for cohesionless or cohesive soils. When adequate soils reports are furnished with shoring plans indicating properties for cohesion in combination with an internal friction angle both properties maybe utilized to increase the effective passive soil resistance.

Passive resistance for individual soldier piles may exceed Rankine theoretical values by a significant amount. For temporary shoring considerations a minimum safety factor is required, so the ultimate load capacity values are to be reducedaccordingly. A minimum safety factor of 1.5 is recommended.

Numerous tests have indicated that soil resistance to horizontal pile loading is greater than that predicted by Rankine equations. For clays the ultimate passive resistance can be as large as 9 to 12 times the shear strength (C), and for cohesionless soils the ultimate resistance can be up to 3 times largerthan Rankine values. The soil resistance acting on isolated piles may be considered to act somewhat as depicted in the sketch at the right.



A combined lateral resisting passive pressure (P_p) equation includes a unitless frictional earth pressure coefficient K_q and a unitless cohesive earth pressure, coefficient k_c, either of which will effectively increase the passive resistance. Any combined lateral resisting passive pressure (P_p) may be defined in equation form as:

$$P_p = d[qK_q + CK_c]$$

Where:
- d = The effective soldier pile diameter
- q = Effective overburden pressure
- K_q = $(\phi/10)K_p \le 3K_p$
- K_p = Coefficient of passive pressure
- C = Soil cohesion = $q_u/2$
- K_c = 0; for $0 \le Z_2 \le 1.5d$ feet
- K_c = $9 + \phi/10 \le 12$ for $Z_2 > 1.5d$
- Z_2 = Depth below excavation

Note That no passive resistance is to be considered for clay above a penetration depth of 1.5d feet.

Arching capability values are included in the Pp equation, no additional arching capability considerations are warranted. The principles defined above can best be demonstrated with the example problem which follows. The alternative surcharge loading of 100 psf (for traffic) is used in the sample problem to reduce its complexity.

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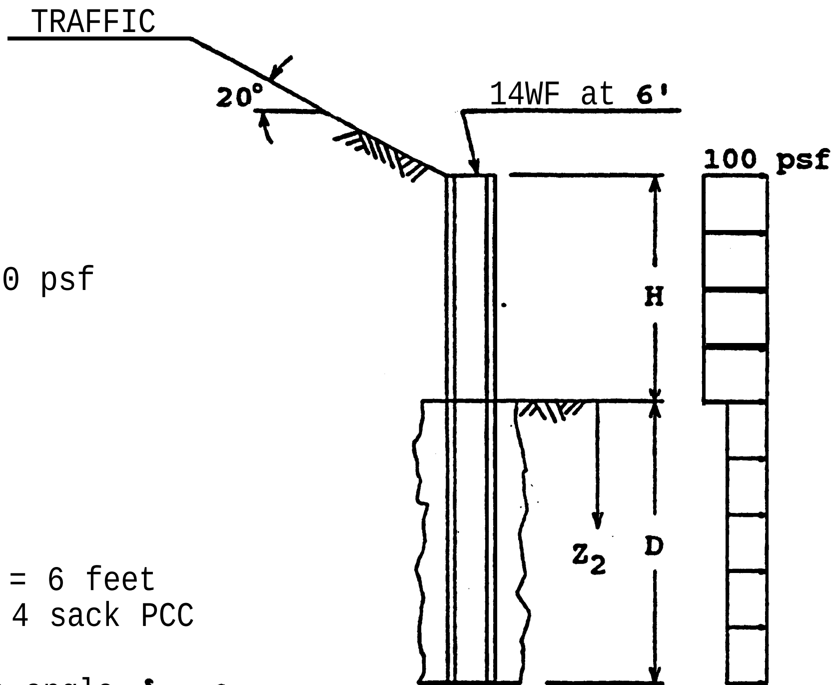
SAMPLE PROBLEM NO. 22 - COMBINED GRANULAR AND COHESIVE SOIL



GIVEN:

Retained Soil:

H = 12 '
γ_1 = 120 pcf
ϕ_1 = 32°
Surcharge = 100 psf

Resisting Soil:

γ_2 = 115 pcf
ϕ_2 = 20°
C_2 = 300 psf

S = Pile Spacing = 6 feet
d = 2'-0" ϕ with 4 sack PCC

Use wall friction angle $\delta = 0$.

SOLUTION:

From FIGURE 8:

For ϕ = 32°	β/ϕ = 0.6	K_{A1} = 0.40
For ϕ = 20°	β/ϕ = 1.0	K_{A2} = 0.97
For ϕ = 20°	β/ϕ = 0.0	K_{P2} = 3.0(0.678) = 2.03

(Use level surface condition at excavation depth)

Active soil pressure above depth of excavationi

$P_A = SK_{A1}\gamma_1 H$ = 6(0.40)(120)(12) = 3,456 Lb/LF

Surcharge = S(100)(H) = 6(100)(H) = 600(H) Lbs

Active soil pressure below depth of excavation:

$$P_A = d(K_{A2}\gamma_1 H + K_{A2}\gamma_2 Z_2 - 2C[K_{A2}]^{1/2})$$

$$P_A = 2\{0.97(120)(12) + 0.97(115)Z_2 - 2(300)[0.97]^{1/2}\}$$

$$P_A = 2(1{,}397 + 112Z_2 - 591) = 1{,}612 + 224Z_2 \text{ Lb/LF}$$

Surcharge = 100(d)(D) = 100(2)(D) = 200(D) Lb

Passive Soil Pressures: (Combined granular and cohesive soils)

$P_p = d(qK_q + CK_c)$ (For 4 or more pile diameter spacing)

Where:

Effective overburden pressure $q = \gamma_2 Z_2 = 115Z_2$ psf
Ultimate $K_q = (20°/10)(2.03) = 4.06 < 3K_p = 9.75$
Working value of $K_q = K_q$/(Safety Factor) $= 4.06/1.5 = 2.71$
$C = 300$ psf
$K_c = 0$ for $0 < Z_2 \leq 1.5d = 3$ feet.
Ultimate $K_c = 9 + \phi/10 \leq 12 = 9 + 2 = 11 < 12$ for $Z_2 > 1.5d$.
Working value of $K_c = K_c$/S.F. $= K_c/1.5 = 11/1.5$

$P_p = d[\gamma_2 Z_2 K_q + CK_c]$

$P_p = 2'[115Z_2(2.71)] = 623.3z_2$ plf for $0 < Z_2 \leq 3'$

$P_p = 2'[115z_2(2.71) + 300(11/1.5)] = 623.3Z_2 + 4400$ plf for $Z_2 \geq 3'$

(No clay can be utilized for passive resistance above Z_2=1.5d=3')

Since the pile spacing for this example problem is 6 feet and the pile diameter is 2 feet the 4 or more pile diameter pile spacing criteria is not met. It will be necessary to prorate between a 4 pile diameter spacing and a condition similar to that of a sheet pile wall.

When the pile spacing effectively equals zero the passive pressure is derived from the following general equation:

$$P_p = \gamma Z_2 K_p + 2C(K_p)^{1/2}$$

For $0 < Z_2 < 3'$: $P_p = \gamma Z_2 K_p = 115Z_2(2.03)$
$= 233.5Z_2$ Lb/LF

For $Z_2 > 3'$: $P_p = 233.5Z_2 + 2(300)(2.03)^{1/2}$
$= 233.5Z_2 + 854.9$ Lb/LF

Proration value: S/4d where S = 6' and d = 2' ∴ Ratio = 6/8 = 3/4

For $0 < Z_2 < 3'$: $P_p = 233.5z_2 + (3/4)(623.3Z_2 - 233.5Z_2)$
$\approx 526Z_2$ Lb/LF

For $Z_2 > 3'$: $P_p = 526Z_2 + 854.9 + (3/4)(4400 - 854.9)$
$\approx 526Z_2 + 3514$ Lb/LF

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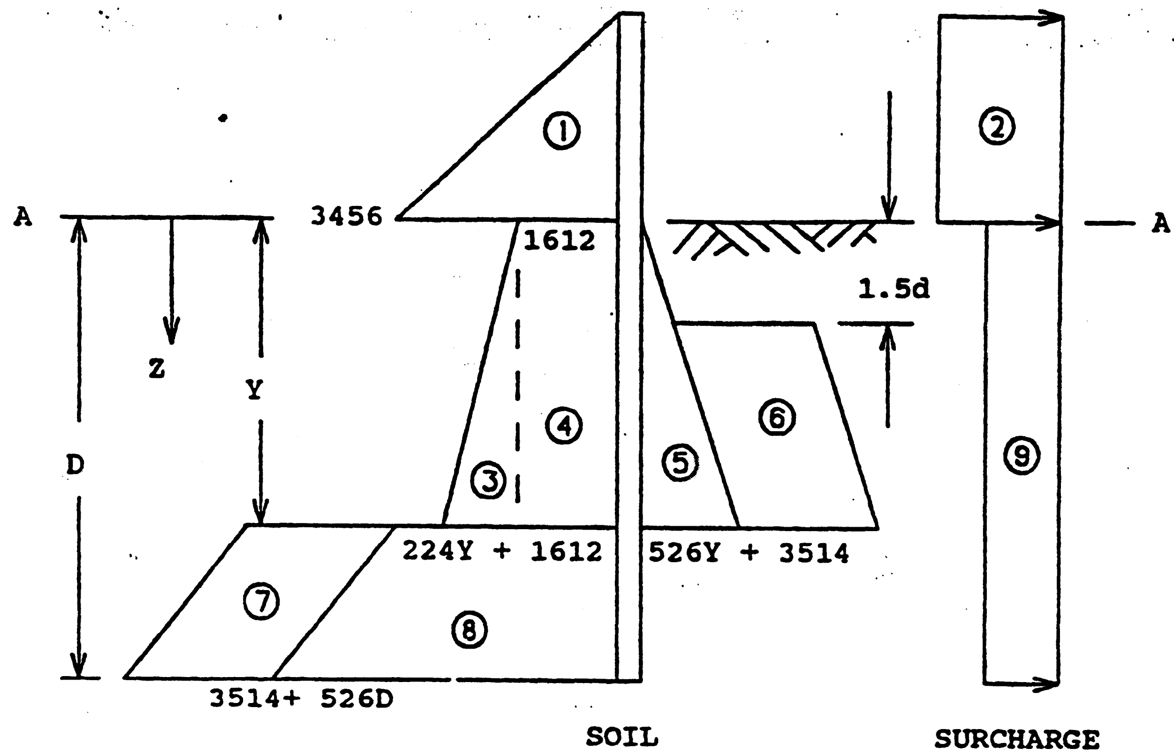

DESIGN PRESSURE (Not to scale)

Areas:

1) $(1/2)(3456)(12)$	$= 20{,}736$
2) $600(12)$	$= 7{,}200$
3) $(1/2)(224)Y^2$	$= 112Y^2$
4) $1{,}612Y$	$= 1{,}612Y$
5) $(1/2)(526)Y^2$	$= 263Y^2$
6) $3{,}514(Y - 3)$	$= 3{,}514Y - 10{,}542$
7) $3{,}514(D - Y)$	$= 3{,}514D - 3{,}514Y$
8) $(1/2)(526)D^2 - 1/2(526)Y^2$	$= 263D^2 - 263Y^2$
9) $200D$	$= 200D$

The sum of the horizontal force must equal zero, $F_H = 0$.

$$F_H = 20{,}736 + 7{,}200 + 112Y^2 + 1{,}612Y - 263Y^2 - 3{,}514Y + 10{,}542 + 3{,}514D - 3{,}514Y + 263D^2 - 263Y^2 + 200D = 0$$

$$= 263D^2 + 3{,}714D - 5{,}416Y - 414Y^2 + 38{,}478 = 0$$

$$= D^2 + 14.12D - 20.59Y - 1.57Y^2 + 146.30 = 0$$

The sum of the moments about A-A must equal zero, $M_{(A-A)} = 0$.

$$
\begin{aligned}
M_{(A-A)} = {} & 20{,}736[12/3] + 7{,}200[12/2] - 112Y^2[2Y/3] - 1{,}612Y[Y/2] \\
& + 263Y^2[2Y/3] + 3514(Y-3)[3 + (1/2)(Y-3)] \\
& - 3514(D - Y)[Y + (1/2)(D - Y)] - 263D^2[2D/3] \\
& + 263Y^2[2Y/3] - 200D[D/2] = 0
\end{aligned}
$$

$$
\begin{aligned}
0 = {} & 82{,}944 + 43{,}200 - 74.67Y^3 - 806Y^2 + 175.33Y^3 + 1{,}757Y^2 \\
& - 15{,}813 - 1{,}757D^2 + 1{,}757Y^2 - 175.33D^3 + 175.33Y^3 - 100D^2
\end{aligned}
$$

$$0 = -175.33D^3 - 1{,}857D^2 + 2{,}708Y^2 + 275.99Y^3 + 110{,}331 = 0$$

$$D^3 + 10.59D^2 - 15.45Y^2 - 1.57Y^3 - 629.28 = 0$$

By trial and error D = 24.26 feet, and Y = 20.45 feet.

Safety factor of 20% to 40% for additional D is not required.

In view of the softness of the clay as indicated in TABLE 13 this answer is not unreasonable.